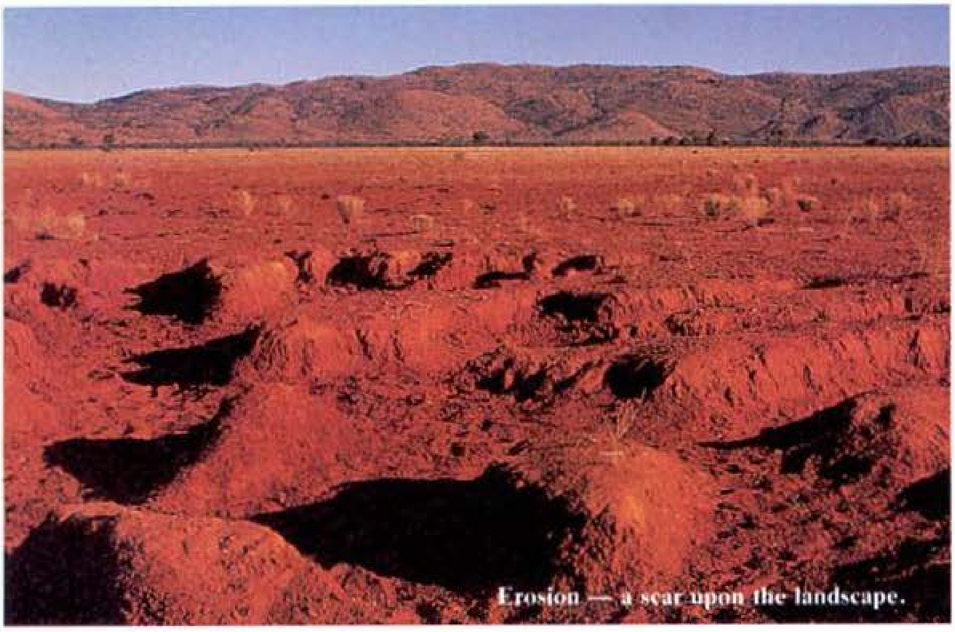
A satellite eye on soil erosion

Scientists at Alice Springs are using microcomputers to process satellite images of Australia's arid lands in order to gauge the extent of soil erosion and to predict where further damage is likely to occur.



Erosion — a scar upon the landscape.

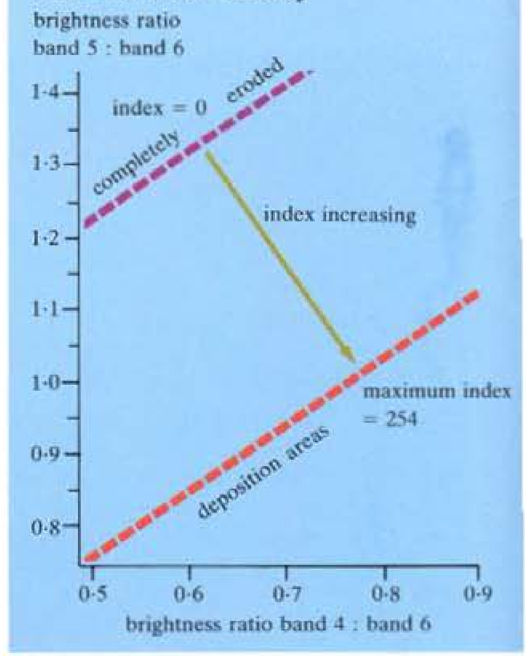
The low-cost technique promises to take satellite monitoring out of the specialised laboratory and into the office of the land manager or soil conservationist. The keys to the system are Landsat scenes on floppy disk, which have recently become available, and micro-BRIAN, a versatile image-processing system developed from CSIRO research.

The parent BRIAN (Barrier Reef Image ANalysis) system was developed at the Division of Water and Land Resources for analysis and mapping of the Great Barrier Reef (described in *Ecos* 31 and 47). Scientists at the Alice Springs laboratory of the Division of Wildlife and Rangelands Research recognised the power of BRIAN for tackling the problem of monitoring and predicting arid-zone soil erosion. Together the two groups created micro-BRIAN, a microcomputer version of BRIAN, which is now available commercially as a general-purpose image-processing system (see the box on page 16).

Erosion prediction

Large areas of arid and semi-arid grazing land are affected by soil erosion, much of it due, at least in part, to high stocking rates. A study in 1978 by the Department of Environment, Housing and Community Development estimated that 13% of Australia's arid grazing land has suffered severe or substantial erosion, while a further 14% has suffered some erosion. The accompanying loss of soil nutrients and

An index of soil stability



The top dotted line corresponds to completely eroded bare soil; the bottom one to silt-deposition areas. A pixel in the continuum between can be assigned a 'soil stability index' depending on its distance from the top line.

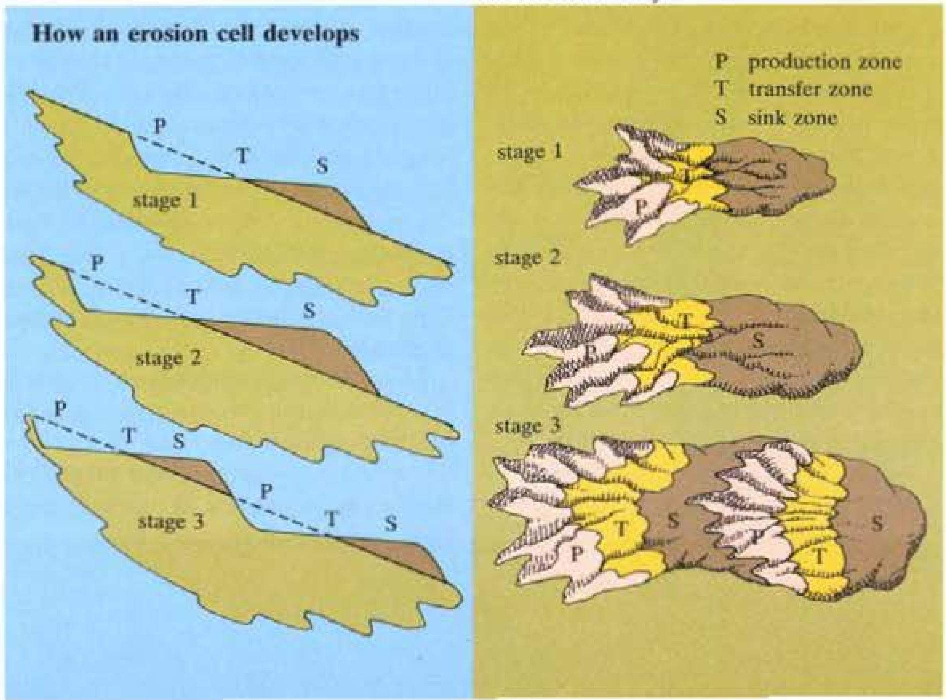
seed stores and the fall in the rate of water absorption have led to declines in the quality and quantity of ground cover. Other consequences include more dust, more frequent flooding and washing out of tracks and fences, and the choking of large areas with soil washed from eroded land.

The ability to predict where in a paddock soil is most likely to erode makes effective counter-measures possible. Graziers can adjust grazing pressure to avoid sensitive areas; they can relocate watering points, adjust paddock fencelines, and reduce stock numbers at critical times.

The system developed by Dr Geoff Pickup, head of the Ecology and Management of Arid Lands Group at Alice Springs, with his CSIRO colleague Ms Vanessa Chewings, allows soil conservationists to gauge the erosion potential of paddocks in a routine way.

An erosion cell comprises three zones: a production zone where soil is eroded, a sink where it is deposited, and a transfer zone in between in which soil loss and gain are in balance. As erosion develops, cells tend to expand in the way shown, rather than new ones beginning.

How an erosion cell develops



For the first time, data covering thousands of hectares can be readily obtained. Using a standard microcomputer, the operator can sift through Landsat scenes looking for the tell-tale signatures of soil erosion, and invoke procedures that will indicate where soil is likely to erode next.

Soil stability index

The reason satellites are so good at picking up erosion in central Australia is the nature of the country here. Because the land is so flat, sheet erosion is the dominant mechanism (channel erosion, usual elsewhere in Australia, is much less frequent). And, since rivers are mostly non-existent, the bulk of the eroded material doesn't get carried far — instead a spell of rain causes it to be transported only a relatively short distance before it is re-deposited.

The result of this process is a landscape with large patches of erosion close to patches of deposition, and Dr Pickup has found that these can easily be distinguished by Landsat.

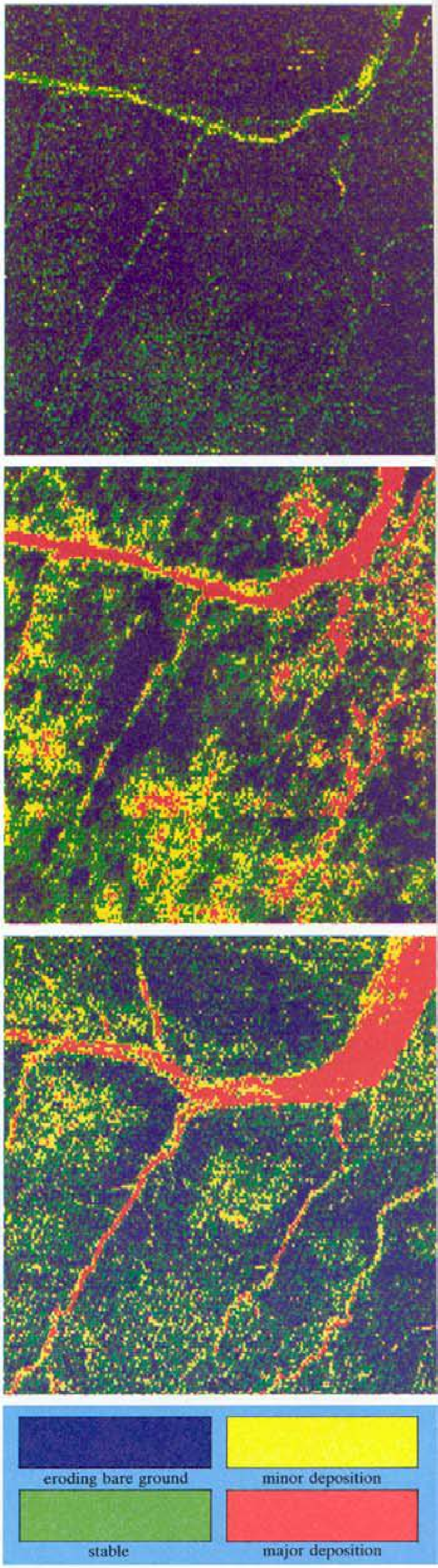
Severe erosion gives rise to bare soil, and this shows up as a high reflectance in all four Landsat wavelength bands. Areas of deposition provide favourable environments for plant growth — good soil and nutrients, relatively abundant moisture, and lots of seeds — and the relatively dense vegetation cover shows up on a Landsat scene as a high 'green index'.

The tell-tale sign of a deposition area — dense vegetation.

Top: A 1972 Landsat image of the Murloocoppie region of South Australia, processed by micro-BRIAN to show erosion index. Purple, indicating eroding bare ground, covers much of the image.

Centre: Using the erosion-prediction routine in micro-BRIAN, the same image was processed to indicate the likely state of the country in 1984. Heavy rain had fallen in the intervening period.

Lower: The actual range condition observed by Landsat in 1984 matches the predicted one quite well.



Actually, Dr Pickup's research has shown that a whole continuum of vegetation changes can be found between these two extremes. If the ratio in brightness between Landsat's band 4 (0·5–0·6 μm) and band 6 (0·7–0·8 μm) is plotted against a similar ratio of band 5 (0·6–0·7 μm) and band 6, then a plot like that reproduced here is obtained.

All the Landsat pixels appear to fall in an area between two parallel lines: those near the top line represent bare, completely eroded areas, whereas those near the bottom line equate with fully vegetated sites.

More significantly, a steady transition occurs as we traverse the distance from the top to the bottom line. Starting from the bare areas at the top, we find the erosion intensity (and rate of soil loss) decreases until we reach the middle, where little soil movement occurs. Descending further, rates of soil deposition increase progressively until the bottom line is reached.

The accuracy of this classification scheme has been confirmed by flying an aircraft over more than 700 sites in central Australia. The plane was fitted with radiometers that responded to the same spectral bands as Landsat. Simultaneously, photographs of the country beneath were taken with a 70-mm camera.

These studies confirmed that the losses and gains of soil parallel changes in both the amount of vegetation cover and its greenness, and that these factors determine where a site falls on the satellite image plot. Extraneous factors such as variations in soil colour, vegetation type, angle of the sun, and absorption of light by the atmosphere have little effect on this arrangement.

Dr Pickup has quantified the satellite readings in a 'soil stability index' — essentially the distance of a point from the upper line of the plot. Small values indicate erosion, medium ones little activity, and large values deposition.

Erosion cells

In central Australia, nearly every erosion site has a corresponding deposition site a short distance away. These are linked in 'erosion cells', each consisting of an eroding area (the source zone), a deposition area (the sink), and an intermediate area (the transfer zone).

Although always comprising linked pairs of sources and sinks, erosion cells form a patchwork mosaic, varying in size from tens of metres to a number of kilometres. Cells can overlie one another, or merge together; they can be partly or fully developed.

Dr Pickup has found that, as erosion continues, it tends to accentuate the existing pattern of cells rather than create new ones. Source areas grow bigger, and so do their corresponding sinks.

If an isolated erosion cell can be discerned, then it is not difficult to predict the course of future erosion. But predicting erosion in the real world requires consideration of a complex mosaic of interlocked and overlaid cells simultaneously changing and interacting with one another.

Dr Pickup has made use of the soil stability index to mathematically define erosion cells and to predict their interac-

Micro-BRIAN: image processing made easy

Micro-BRIAN is designed for use on a 16-bit microcomputer (an IBM personal computer, or one of its look-alikes). For $33 000 complete (hardware and software), you can manipulate images in the same way as you can with systems costing many times more — albeit a little more slowly.

Micro-BRIAN was developed with the specific intention of taking image processing away from large centralised computer systems and putting it into the offices of the end user. Now that the Australian Landsat Station is providing Landsat images on floppy disk, many owners of personal computers can get into the remote-sensing field.

The system was designed with the non-specialist in mind (it's 'user friendly', as they say), and each application module is supported by a 'recipe book'. Applications include shallow-water mapping, land cover mapping and monitoring, image rectification, and arid-land erosion mapping and modelling.

Micro-BRIAN's forerunner BRIAN — the Barrier Reef Image ANalysis system — was conceived by Dr David Jupp and his colleagues at the CSIRO Division of Water and Land Resources. Then, together with scientists at the Division of Wildlife and Rangelands Research, they transformed it into the commercial micro-BRIAN package — equally suited to monitoring crops, forests and other vegetation, or erosion. Microprocessor Applications Pty Ltd also helped in creating commercial-standard software. Micro-BRIAN can process images from NOAA, SPOT, and other satellites as well as Landsat.

A range of Australian institutions have acquired micro-BRIAN units, and MPA expects to sell hundreds of units in South-East Asia and the Pacific region. Recently, the system has been launched on the North American market.

The CSIRO group at Alice Springs is a keen user of micro-BRIAN. A number of projects related to the erosion studies are under way.

All you need to do your own image processing. A complete micro-BRIAN set-up costs about $30 000.

Mr Barney Foran is using the system to examine the accuracy with which Landsat can monitor changes in vegetation cover across tracts of arid land. He has found a high correlation between Landsat radiance data and amount of cover, even down to cover as low as 10%. This work promises to provide an excellent way of looking at the effect of grazing pressures.

Mr Graham Griffin and Mr Grant Allan are using Landsat images to map the fire histories of arid land, assess its current fuel load, and forecast the intensity of a fire if the vegetation — mostly spinifex — should catch alight. They are looking at the possibility of reintroducing the type of fire regime that existed before European settlement, when frequent small fires created an ecologically diverse mosaic of recently burnt and long-since-burnt country. (See 'Fire in the Centre' in *Ecos* 40.)

One approach they are examining is to outfit an aircraft with a scanning radiometer, making it possible to immediately assess the length of time since an area burnt. If it's ripe for burning, then an aerial incendiary could be released.

At the Division of Water Resources in Canberra, micro-BRIAN is also being put to good use in a number of studies. In the realm of soil erosion, scientists are using it to monitor the vegetation cover of areas in outback New South Wales and southern Queensland, and to pick out areas in the Burrinjuck catchment near Yass, N.S.W., that may be eroding and contributing sediment to the water storage.

In addition, the Division is supporting a visiting Chinese scientist's application of micro-BRIAN to the study of erosion in the Lowess Plateau area of north-western China.

Other approaches to image processing

Much expertise in image processing has been built up by CSIRO. As well as micro-BRIAN, another image-processing system derived from CSIRO research has recently become available commercially.

The high-performance Arlunya IW1000 work-station is being marketed by the Dindima Group Pty Ltd, and it evolved from the satellite-image reception and analysis system developed by the CSIRO Division of Atmospheric Research. The Division's CSIDA facility (CSIRO System for Interactive Data Analysis) was described in *Ecos* 41.

The Arlunya system's strength lies in its flexible software developed by Dr John O'Callaghan and his colleagues at the CSIRO Division of Information Technology. Combined with a high-speed computer and special-purpose display hardware designed by Dindima, this enables the system to construct and manipulate image data at great speed.

The Arlunya IW1000 has been designed to be fully compatible with another element of the CSIDA technology, a satellite-tracking dish with receiver called SAT-TRAC, which is being marketed by its co-developer, PCM Electronics Pty Ltd. Data received through SAT-TRAC's 2·4-m parabolic dish can be processed by the Arlunya work-station 'on the fly' — that is, within moments of its reception. The benefit is a considerable reduction in data storage requirements.

Dr O'Callaghan is continuing work on image processing and advanced computer graphics at the Division's newly established Centre for Spatial Information Systems in Canberra. The Centre has acquired a Domain Computer advanced graphics work-station to facilitate its research. Applications for this research include terrain analysis, molecular modelling, structural and civil engineering, and computer animation.

Another major activity at the Centre is work on geographic information systems, in which many sets of geographic data — for example, topographic and ecological — are integrated and stored relative to precise spatial co-ordinates. One such system is LIBRIS — Land Image-Based Resource Information System — developed by Dr Dean Graetz of the CSIRO Division of Wildlife and Rangelands Research, and described in *Ecos* 33.

Dr O'Callaghan and Dr Graetz are working together to expand LIBRIS' capabilities in analysing the condition of the semi-arid rangelands of southern Australia from Landsat images. LIBRIS has already shown that the effect of grazing intensity can be discerned from Landsat images of areas near Broken Hill, N.S.W., and that areas prone to erosion (slope being the prime factor) can be broadly specified.

Now they want to see whether statistical relations between pixels can give more specific information on vegetation cover and erosion. This could allow an early warning of impending rangeland degradation — through drought and overstocking — to be produced. A system of Australia-wide drought monitoring is also being assessed using data from the NOAA satellites.

The application of Landsat image data to rangeland assessment and monitoring: the development and demonstration of a land image-based resource information system (LIBRIS). R.D. Graetz, R.P. Pech, M.R. Gentle, and J.F. O'Callaghan. *Journal of Arid Environments*, 1986, **10**, 53–80.

Degraded land in the Centre, stripped of vegetation and topsoil.

tion. He and Ms Chewings have written a set of computer programs, now part of the micro-BRIAN system, that looks both for underlying patterns of change across the whole scene and for strong correlations between activity in individual pixels and in their immediate neighbours. In this way, the abundance and average size of erosion cells in a scene can be determined.

When the effect of continued erosion is simulated, the average of the soil stability indexes becomes lower, while their variability increases, reflecting the presence of more erosion and more deposition. Correlations between neighbouring pixels also increase, due to the intensification and expansion of erosion cells.

Dr Pickup's technique makes it possible to predict erosion effects over a whole paddock by drawing on data for an area with similar soils and vegetation that is already more eroded. Appropriate parameters for the mathematical model relating to the more-eroded area can be extracted, and applied to the paddock under investigation. The end result is equivalent to saying, 'if you use this area in the way that one was used, then this will be the result'.

Dr Pickup has tested the prediction technique using Landsat scenes of gibber country, floodplain, and alluvial footslope taken in 1972. When the predictions were compared with actual Landsat images taken in 1984, there was good agreement between the two, as the illustrations show. Locations of newly eroded areas matched, and the general trend was also correct.

Future developments include the addition of routines to model the effect of grazing animals. This work, being done with Divisional colleague Dr Mark Stafford Smith, will allow specified grazing pressure distributions to be combined with erosion risk maps, and so the effect of different paddock layouts can be simulated.

Another development under way is the design of an image-processing system that can operate in 'real time'. The system would acquire an image from a video camera and, in a matter of seconds, compare it with a previous image. In this way, Dr Pickup hopes it will become possible to check on the condition of rangeland by flying over it in an aircraft equipped with a video camera sensitive to particular wavebands.

Andrew Bell

More about the topic

Mapping and forecasting soil erosion patterns from Landsat on a microcomputer-based image processing facility. G. Pickup and V.H. Chewings. *Australian Rangelands Journal*, 1986, **8**, 57–62.

The erosion cell — a geomorphic appr›ach to landscape classification in range assessment. G. Pickup. *Australian Rangelands Journal*, 1985, **7**, 114–21.

Use of Landsat radiance parameters to distinguish soil erosion, stability, and deposition in arid central Australia. G. Pickup and D.J. Nelson. *Remote Sensing of Environment*, 1984, **16**, 195–209.

Monitoring the health of the arid inland. J. Seymour. *Ecos* No. 33, 1982, 16–23.